Radioactivity in Everyday Life

S. G. Hutchison
Department of Chemistry, University of Idaho, Moscow, ID 83844-2343

F. I. Hutchison
Environmental Health and Safety, University of Idaho, Moscow, ID 83844-2030

It is an inescapable fact—you are exposed to radiation from the moment of conception until the day of your death. The planet Earth is a radioactive planet. The air you breathe, the ground you walk on, the water you drink, the place you live—essentially the entire environment surrounding you contains radioactivity. You may use products containing radioactive materials, sometimes without even knowing it. In addition, you may voluntarily choose to receive some radiation exposure during the course of medical diagnosis and medical treatments. Should you be worried? Probably not.

Radiation we are exposed to all our lives comprises what is called background radiation. The majority of this radiation is naturally occurring and arises from three sources. Radiation that originates from the sun and from outer space is called cosmic radiation. Cosmogenic radiation is radiation that comes from radioisotopes formed in the atmosphere. The third source of naturally occurring radiation originates from primordial radionuclides (radioactive elements that have always been present in the earth) and is called terrestrial radiation. Of the 340 isotopes found in nature, only about 70 are radioactive, including all isotopes with atomic numbers greater than 83. Many of these radionuclides are not significant contributors to our radiation exposure because of their low isotopic and/or elemental abundance.

Most of us have had an X-ray at least once during our lives. The dentist uses X-rays to monitor the health of our teeth. The doctor uses X-rays as a diagnostic tool to detect problems within our bodies and as a form of treatment for some diseases. Radioactive materials can also be used by the doctor for diagnosis and treatment.

Human activities have contributed radioactive materials to the environment through nuclear weapons testing and nuclear accidents. Open-air nuclear weapons testing from the mid-1940s to the 1980s dispersed radioactive fallout on a global scale and has contributed to our background radiation dose. More recently, nuclear reactor accidents such as the one that occurred at Chernobyl have also increased background radiation.

Some consumer products contain radioactive materials or can produce radiation. Often the consumer is unaware that radioactive materials are used in the product, or that some electrical products can generate radiation. There are a variety of reasons that commercially available consumer products may contain radioactive materials or produce ionizing radiation. Often, the presence of the radioactive material is needed to make the product function properly; for example, smoke detectors. Some products, such as television receivers and video display terminals, produce ionizing radiation. Radioactive materials are naturally present in other products—for example, tobacco and combustible fuels. Since laws do not require the presence of naturally occurring radioactive materials to be explicitly listed on many of these products, consumers are often unaware that the products they are using may contain radiation.

In spite of the fact that Earth has always been and will continue to be radioactive, and that nuclear power and radioactive waste disposal will remain environmentally controversial topics, many students are not getting basic information concerning radioactivity. Nuclear chemistry is often covered in a general chemistry course at the end of the semester, on a time permitting basis. The argument usually is that there is so much material to cover in general chemistry and so little time to cover it, something has to be left out and often nuclear chemistry is a deleted topic. However, a basic understanding of radiation may be as useful to the typical student as many of the other topics we so adamantly cover. The term "nuclear" does not have to have negative connotations.

This paper is intended to provide the reader with the information necessary to gain an understanding of radioactivity in everyday life. In particular, this paper will concentrate on naturally occurring radiation and radiation in consumer products. Although there are many consumer products that could be covered, we chose to discuss those that are of general interest as well as those which could be easily demonstrated in a lecture setting to be radioactive. Students are often amazed to hear the clicks when many of these products are held up to a Geiger counter.

Radiation Exposure and Dose

Three common terms are used to describe radiation exposure or radiation dose: the roentgen, the rad, and the rem. The *roentgen* (R) is a unit of exposure and is only used to define an external exposure from X-rays and gamma rays. A roentgen is sufficient radiation to produce 2.58×10^{-4} coulombs of charge per kilogram of air.

We are concerned, however, with the effect of radiation energy on our bodies, not air. The *rad* is an acronym for **r**adiation **a**bsorbed **d**ose and is used to describe the amount of any type of radiation energy deposited in any medium. It is defined as 0.01 joules of energy deposited in one kilogram of any medium. In air, one rad equals approximately 0.87 roentgens but, in soft tissue, one rad of X-ray or gamma radiation is essentially equivalent to one roentgen. Attempts are being made to replace the rad with an international (SI) unit called the gray (Gy). One *gray* equals one joule of energy per one kilogram of any medium; or, one gray is equivalent to 100 rads.

Because different types of radiation will cause different biological effects for the same amount of energy deposited within our bodies, the rem was developed to take this effect into account. The *rem* (**r**oentgen **e**quivalent **m**an) is the rad multiplied by a quality factor. This quality factor is based on the biological effects or damage received from the different types of radiation relative to those caused by gamma rays or X-rays. Gamma rays, X-rays, and beta particles have a quality factor of one, neutrons have a quality factor of ten, and alpha particles, twenty. Thus, for a given amount of energy, alpha particles will be twenty times more harmful to humans than the same amount of energy re-

ceived from gamma rays. The SI equivalent for the rem is the *sievert* (Sv), which is equal to 100 rems.

Ionizing counters, such as the Geiger counter and scintillation counters, can be used to count the particles given off from radioactive materials. The rate of nuclear disintegrations occurring in a radioactive material is the activity of the material. A *curie* (Ci) is an activity unit equal to 3.7×10^{10} disintegrations per second. The *becquerel* (Bq), which is the SI unit comparable to the curie, equals one disintegration per second.

The federal Nuclear Regulatory Commission (NRC) allows the general public to receive a radiation dose of 0.1 rem (100 millirems) per year (*1*). This limit is in addition to the radiation dose received from background radiation and for medical reasons.

Naturally Occurring Radiation

Cosmic Radiation

Solar radiation contributes very little to the overall dose received from cosmic radiation. However, as high-energy cosmic radiation, mainly protons and alpha particles, interacts with the upper atmosphere, it creates a secondary cosmic radiation to which we are exposed. At sea level, the average annual dose from cosmic radiation is about 26 millirems (mrem) per year (*2, 3*). For each 100-meter increase in altitude, this annual dose increases by approximately 1.5 mrem. This increase occurs because, as elevation increases, there is less atmosphere to shield the secondary cosmic radiation.

As might be expected, persons on long, high-altitude airplane flights receive an additional dose because of the increased exposure to radiation at high altitudes. A person traveling from Los Angeles to Paris on a conventional flight can receive almost 10 mrem of radiation (*3*).

Cosmogenic Radiation

Radionuclides formed by the interaction of cosmic rays with atoms in the atmosphere are known as cosmogenic radionuclides. When cosmic rays interact with gases in the upper atmosphere particles from the nucleus of an atom, such as neutrons and protons, are released. These secondary particles, in turn, form the cosmogenic radionuclides through nuclear reactions. Carbon-14 is the most significant of the cosmogenic radionuclides. Tritium (hydrogen-3), beryllium-7, and sodium-22 are cosmogenic radionuclides that make minor contributions to our radiation exposure. Although these cosmogenic radioisotopes have relatively short half-lives, they are always present in our environment because they are continuously being produced. The average annual radiation dose received from cosmogenic radiation is approximately 1 mrem per year. Essentially all of that dose is due to carbon-14 present in tissues (*2, 3*).

Carbon-14 is formed in the upper atmosphere according to the reaction:

$$^{14}_{7}\mathrm{N} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{14}_{6}\mathrm{C} + {}^{1}_{1}\mathrm{H} \qquad (1)$$

In the atmosphere, carbon-14 is present in carbon dioxide. When it reaches the earth it becomes part of the carbon cycle and distributes itself accordingly. Since we continuously eat and breathe carbon-containing matter, we will always have some carbon-14 in our bodies. Carbon-14 is also produced by thermonuclear explosions. Carbon-14 is a radioactive isotope of carbon, has a half-life of 5730 years and decays by beta emission:[1]

$$^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + \beta^{-} + \bar{\nu} \qquad (2)$$

The specific activity of carbon-14 in "natural" samples has been assumed to be relatively constant at 7.5 pCi/g of total carbon for at least 15,000 years, prior to the advent of nuclear weapons testing. The average dose received from carbon-14 due to weapons tests is believed to have reached a peak of 0.96 mrem/year in 1965 (*4*).

In the upper atmosphere, tritium ($^{3}_{1}\mathrm{H}$) is formed according to the reaction:

$$^{14}_{7}\mathrm{N} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{3}_{1}\mathrm{H} \qquad (3)$$

Tritium is predominately found in the atmosphere in water vapor. Eventually it falls to earth in rain or snow. Like carbon-14, tritium is also produced by thermonuclear explosions. Tritium is a radioactive isotope of hydrogen having a half-life of 12.3 years. It decays by beta emission:

$$^{3}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{H} + \beta^{-} + \bar{\nu} \qquad (4)$$

In nature, about 1 atom of tritium exists for every 10^{18} atoms of $^{1}\mathrm{H}$. Because we are continuously ingesting foods and drinks containing hydrogen we will always have trace amounts of tritium in our bodies. The tritium that is present in our bodies is uniformly distributed in all tissues. The radiation dose received from tritium is extremely small, approximately 1 μrem per year (*3*).

Beryllium-7 and sodium-22, which are produced by cosmic radiation as well as by thermonuclear explosions, have not been studied as extensively as carbon-14 and tritium and are not major contributors to our radiation exposure. The average annual dose commitments received from beryllium-7 and sodium-22 are estimated to be 3 μrem and 0.4 μrem, respectively (*3*). The annual dose commitment is the dose received over 50 years from one year's intake of the isotope.

Terrestrial Radiation

Terrestrial radiation arises from radioisotopes whose half-lives are comparable to the age of the earth (sometimes called primordial radionuclides) and from the decay products of those long-lived isotopes. Most of the terrestrial radiation to which we are exposed comes from members of the uranium decay series, members of the thorium decay series, and from singly occurring potassium-40 and rubidium-87. The average annual radiation dose received from terrestrial radiation is approximately 28 mrem externally and 240 mrem internally (*2, 3*).

The uranium decay series begins with uranium-238, which has a relative isotopic abundance of 99.27% and a half-life of 4.468×10^{9} years. Uranium-238 is an alpha emitter that undergoes a series of alpha and beta decays before forming the stable lead-206 isotope. The thorium decay series begins with thorium-232, which has a half-life of 1.405×10^{10} years and a relative abundance of essentially 100%. Thorium-232 is an alpha emitter that undergoes a series of alpha and beta decays before forming the stable lead-208 isotope.

Potassium-40 has a relative isotopic abundance of 0.0118% and a half-life of 1.3×10^{9} years. Potassium-40 decays by beta emission and also by electron capture:[2]

$$^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{20}\mathrm{Ca} + \beta^{-} + \bar{\nu} \quad (89.3\%) \qquad (5)$$

$$^{40}_{19}\mathrm{K} + \mathrm{e}^{-} \rightarrow {}^{40}_{18}\mathrm{Ar} + \nu \quad (10.7\%) \qquad (6)$$

Our bodies require potassium; and since potassium-40 is present in natural potassium, it is a natural component of foods and is present in human tissues in small amounts.

Even though the isotopic abundance of potassium-40 in natural potassium is very low, potassium-40 is a major contributor to the radiation dose received from natural sources because potassium is one of the ten most surface-abundant elements on earth. The external radiation dose that can be expected due to potassium-40 is about 12 mrem per year (*5*). Internally, the annual radiation dose ranges from 14 mrem for bone surfaces, to 18 mrem for soft tissue, to 27 mrem to bone marrow (*3*).

Rubidium-87 has a relative isotopic abundance of 27.8% and a half-life of 4.8×10^{10} years. Rubidium-87 is present in most soils and decays by beta emission:

$$^{87}_{37}\mathrm{Rb} \rightarrow {}^{87}_{38}\mathrm{Sr} + \beta^- + \bar{\nu} \qquad (7)$$

Rubidium-87 is not an important source of external radiation exposure. An estimated annual internal dose from rubidium-87 has been reported to range from 0.3 mrem for soft tissue, to 0.7 mrem to bone marrow, to 1.4 mrem to bone surfaces (*3*).

The air we breathe contains a number of radioactive isotopes. One of these, radon gas, is formed by the decay of radium, which is present in most soils and rocks.

$$^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + \alpha \qquad (8)$$

Although there are several radon isotopes, radon-222 is the most common and has the longest half-life (approximately 3.8 days).

Radon gas migrating through the soil can enter buildings and residences through dirt floors, cracks in concrete floors and walls, floor drains, sumps, joints, and cracks or pores in hollow-block walls. Radon in buildings can also originate from building materials. Gypsum and calcium silicate slag building materials, stone fireplaces, and solar heating using rock beds are all possible sources of radon. Small amounts of radon dissolved in groundwater and in natural gas supplies can be released into the home during use.

The isotopes of radon have fairly short half-lives and by themselves are not major contributors to naturally occurring radiation exposure. Most of the radon that we breathe in is subsequently exhaled. The problem with radon lies in the fact that radon decays to radioactive solids, which may become trapped in the lungs. It is these decay products, mainly isotopes of polonium and lead, that make a large contribution to the radiation dose received by man. It has been estimated that radon and its decay products contribute approximately 200 mrem per year to the average dose received by individuals (*2, 3, 6*). This is by far the most significant contributor to the average radiation dose that we receive from natural radioactivity. Although there is a large uncertainty range in this number, the Environmental Protection Agency (EPA) has estimated that approximately 14,000 lung cancer deaths per year in the United States can be attributed to radon exposure (*7*).

In recent years, an increasing awareness concerning radon exposure and radon levels in buildings has occurred (*7–13*). The EPA-recommended action level for radon remediation of a building is 4 pCi/L of air, based on an annual average concentration of radon (*7*).

The total estimated annual dose from cosmic rays, cosmogenic radionuclides, and primordial radionuclides in "normal" regions is about 56 mrem per year externally and about 240 mrem per year internally, giving a total exposure of about 300 mrem per year from natural radiation (*2, 3*). Obviously, where you live is important in determining the actual amount of radiation exposure you receive.

Radiation from Consumer Products

Radioluminescent Paint

The first use of radioactive substances in manufactured products was in luminous paint. Substances that, after being excited by radiation, give off light as electrons return to lower-energy states are known as radioluminescent compounds or phosphors. The luminescent properties of radium, an alpha emitter, had been established prior to World War I. It was known that when a small amount of radium sulfate was added to a zinc sulfide suspension, the resulting material glowed. Paints, based on the luminescent properties of radium, were used during and after World War I to paint the dials of timepieces, compasses, aircraft instruments, and other such devices. The painters, mostly young women, would use their lips to point the brushes before painting the numbers. The first cases of "radium jaw", the bone cancer observed among radium dial painters, were observed in 1924. Eventually, the connection between radium and the bone cancers was made. It has been reported that the last radium-containing wristwatches were produced in about 1968 and the last radium-containing clocks were produced in about 1978 (*14*). We have an old clock and an old watch that we use to demonstrate the radioactive content of these products.

Tritium and promethium-147, which are regulated by the NRC, have essentially replaced radium in radioluminescent paints. Tritium and promethium-147 are both beta emitters. Promethium-147 decays with a maximum energy of 224 keV and tritium decays with a maximum energy of 18 keV. The low-energy beta particles released by these radioisotopes are expected to be stopped by the cases of timepieces using these materials.

Radioluminescent Signs

Instead of radium, tritium gas, contained in sealed glass tubes that have been coated on the inside with a phosphor such as zinc sulfide, is very commonly used to provide luminescence in a variety of "glow in the dark" items. Aircraft and building exit signs are perhaps the most common of these items. According to the NRC, these items may contain up to 25 curies of tritium (*14*). Since the container absorbs the emitted beta particles, exposure to the public is minimal unless leakage or rupture of the container occurs.

Camping Lantern Mantles

Many people have used camping lanterns. Most people are surprised to learn that the familiar glow produced by lantern mantles is due to the presence of thorium and nonradioactive cerium. When the mantle is first burned, thorium and cerium compounds present in the mantle are converted to cerium and thorium oxides. The luminescence from the mantle occurs because these oxides remain solids even though they burn at very high temperatures (*15*). The thorium contained in lantern mantles does not pose much of a problem when it is external to the body. Your skin will stop the alpha particles that are emitted. The potential problems occur after the mantle has been ashed and it is being removed. Care must be taken so that the radioactive ash does not get inhaled or consumed. Once lodged in the lungs the ash can be extremely biologically damaging. Recently, thorium-free lantern mantles have become commercially available. Samples of both the thorium and thorium-free mantles can be purchased for demonstration purposes.

Smoke Detectors

Although radium was initially used, americium-241 (an alpha emitter) is currently used in most ionization-type

smoke detectors. In this type of smoke detector, the air between two electrodes in an ionization chamber is ionized by a radioactive source—the americium-241. When the electric current that flows between the two electrodes is reduced by the presence of smoke particles, an alarm sounds. It is estimated that the average annual radiation dose received from household use of smoke detectors is between 0.9 and 5 μrem (*14*). The benefits of owning and properly using a smoke detector far outweigh any potential hazards associated with the presence of the radioisotope in the detector. Smoke detectors are much more likely to save your life than they are to cause damage to you from radiation. Smoke detectors can be easily obtained for demonstration purposes.

Ceramics and Glassware

Owing to their ability to produce a wide variety of colors, uranium compounds have been used to add color to ceramic glazes. Colors ranging from blacks, browns, greens, and various hues in the yellow to red range can be obtained in glazes from sodium uranite and various uranium oxides. Uranium compounds also add color and give fluorescent and iridescent properties to glassware. For example, glass becomes increasingly opaque as the concentration of uranium in it is increased. The use of uranium in glassware to give it color and opacity was popular until the 1940s, when the availability of uranium became limited owing to the war effort. When uranium became needed in the war effort, manufacturers of ceramics and glassware were forced to find other substances to use in these products. It turned out that many of these alternate choices were more economical to use than uranium, and its use in glassware and ceramics did not return to previous levels after the war. Most glassware and ceramics can still contain up to ten percent (by weight) uranium or thorium. Glazes can contain up to twenty percent (by weight) uranium. Even though it is allowed, uranium is seldom used in these products anymore (*14*). For demonstration purposes, we have a piece of depression-era glass, which contains detectable amounts of radioactivity, and an old bright-orange-glazed Fiestaware plate, which gives off an extremely large amount of radiation. A recently purchased orange Fiestaware plate does not contain detectable amounts of radiation.

Salt Substitute

Many people need to restrict the amount of sodium in their diets. The commonly purchased salt substitute is potassium chloride. As previously mentioned, naturally occurring potassium contains the radioactive isotope potassium-40, at a natural abundance of 0.0118%. Thus, potassium chloride salt substitute contains a small percentage of this isotope. The specific activity of a radioisotope (SA_i) in units of Ci/g is given by:

$$SA_i = \frac{M_{Ra} \times t_{1/2,Ra}}{M_i \times t_{1/2,i}} \qquad (9)$$

Where M_{Ra} is the atomic mass of radium-226 (M_{ra} = 226 amu), M_i is the atomic mass of isotope i, $t_{1/2,Ra}$ is the half-life of radium ($t_{1/2,Ra}$ = 1,600 years), and $t_{1/2,i}$ is the half-life of isotope i in years. For potassium-40, which has an atomic mass of 40 amu and a half-life of 1.3×10^9 years, the specific activity is 7.0 μCi per gram of potassium-40. This leads to a specific activity for a salt substitute sample of 4.4×10^{-4} μCi per gram of pure KCl.

A container of KCl salt substitute can be purchased for demonstration purposes. Although the amount of radiation given off by this salt substitute is small, it can be detected at levels slightly above background.

Table 1. Distribution of Sources of Radiation Exposure

Source	Exposure (%)
Natural Sources	
Radon	55
Cosmic radiation	8
Terrestrial radiation	8
Internal radiation	11
Man-Made Sources	
Medical X-rays	11
Nuclear medicine	4
Consumer products	3
Occupational exposure, nuclear fallout, nuclear fuel cycle, other sources	<1
Total	*100*

Dental Products

Porcelain dental products, such as dentures and crowns, contain feldspar minerals that contain naturally occurring potassium (in $KAlSi_3O_8$). The amount of radiation a wearer of such dental materials receives from potassium is very small and the benefits of having these dental products available outweighs the small radiation dose received from the product. However, in addition to potassium, some of these products also contain uranium. Uranium has been added to some denture materials in very small amounts to give them a natural color and fluorescence (the "pearly white" appearance associated with teeth) (*16*). While the amount of potassium in dental products is not regulated, the amount of uranium in these products is; it cannot exceed 0.05%, by weight (*17*). Domestically, uranium is no longer added to porcelain. We have not found detectable amounts of radiation in dental products that we have examined.

Tobacco Products

Of all the consumer products that individuals have reasonable control over, tobacco products, in all probability, contribute the highest radiation dose. Tobacco and cigarette smoke have been found to contain the radioisotopes lead-210 and polonium-210. It appears that these radioisotopes are picked up by the tobacco plants when radon decay products are deposited on the large leaves of the plants. It does not appear that the plants pick up a significant amount of these isotopes through their root system (*14*).

Fairly recent studies indicate that smokers and nonsmokers who are exposed to secondhand smoke may encounter increased exposure to radon and its decay products from air as well as from tobacco smoke. Apparently smoke particles, which can remain suspended in the air for a day or so, provide a surface for the decay products of radon present in the air to adhere to and they can subsequently be inhaled (*18*).

It is hard to estimate the average dose received from tobacco products, since exposure depends so much on the individual. Obviously, the site of greatest damage from radiation is the lungs, where radioactive particles can become lodged. Radiation exposure, however, is not the major contributor to the risk of developing lung cancer from tobacco products. The chemical and physical properties of tobacco products appear to be the greater contributor to this risk. The risk of developing fatal lung cancer is about 3–9% for smokers and about 0.5% for nonsmokers (*2*).

Conclusion

It should be obvious that exposure to ionizing radiation cannot be totally avoided. However, individuals can minimize their exposure by becoming knowledgeable about radiation and its effects. A typical person in the United States can expect to receive an average radiation dose of about 360 mrem (3.6 mSv) per year. Of this dose, 82% is from natural sources and 18% from man-made sources. The contribution from the various sources of radiation to the total radiation exposure of a typical person in the United States is shown in Table 1 (*6*).

In writing this paper we have tried to put into perspective radioactivity and radiation exposure and to remove some of the negative connotations that have been associated with these terms. For several years, we have introduced the material described in this paper in presentations, using slides and demonstrations with a Geiger counter, to general chemistry classes in order to give students a general overview and understanding of radioactivity. While this type of presentation will not make students experts in nuclear chemistry, it should be enough to give them a greater awareness and fundamental understanding of what radiation and radioactivity are all about.

Notes

1. Particles called antineutrinos, $\bar{\nu}$, are emitted along with beta particles. Antineutrinos have no charge and a mass much smaller than the mass of an electron. Antineutrinos contain a portion of the kinetic energy that is released during the decay process.

2. Particles called neutrinos, ν, are emitted when an orbital electron is captured. Neutrinos, like antineutrinos, have no charge and a mass much smaller than the mass of an electron. The neutrino emitted in electron capture is monoenergetic and carries away excess energy.

Literature Cited

1. Code of Federal Regulations, **1995**, Title 10, Part 20.
2. *Ionizing Radiation Exposure of the Population of the United States: 1987*; National Council on Radiation Protection and Measurements; U.S. Government Printing Office: Washington, DC, 1987; Report No. 93.
3. *Exposure of the Population in the United States and Canada from Natural Background Radiation: 1987*; National Council on Radiation Protection and Measurements; U.S. Government Printing Office: Washington, DC, 1987; Report No. 94.
4. Eisenbud, M. *Environmental Radioactivity*, 3rd ed; Academic: Orlando, 1987.
5. *Principles for Limiting Exposure of the Public to Natural Sources of Radiation*; International Commission on Radiological Protection; Pergamon: New York, 1983; Publication 39.
6. National Research Council, Committee on the Biological Effects of Ionizing Radiation (BEIR V). *Health Effects of Exposure to Low Levels of Ionizing Radiation*; National Academy: Washington, DC, 1990; pp 18–19.
7. Radon Division, Office of Radiation Programs, U.S. Environmental Protection Agency. *Technical Support Document for the 1992 Citizen's Guide to Radon* (EPA 400-R-92-011), 1992.
8. *A Citizen's Guide to Radon*. 2nd ed.; United States Environmental Protection Agency, Office of Air and Radiation; U.S. Government Printing Office: Washington DC, 1992; 402-K92-001.
9. Martin, R. B. *J. Chem. Educ.* **1991,** *68*, 275–276.
10. Atwood, C. H. *J. Chem. Educ.* **1992,** *69*, 351–355.
11. Luckenbaugh R. W. *J. Chem. Educ.* **1994,** *71*, 902.
12. Atwood, C. H. *J. Chem. Educ.* **1994,** *71*, 903.
13. National Research Council, Committee on the Biological Effects of Ionizing Radiation (BEIR IV). *Health Risks of Radon and Other Internally Deposited Alpha-Emitters*; National Academy: Washington, DC, 1988.
14. *Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources: 1987*; National Council on Radiation Protection and Measurements; U.S. Government Printing Office: Washington DC, 1987; Report No. 95.
15. Breedlove, C. H. *J. Chem. Educ.* **1992,** *69*, 621.
16. Thompson, D. L. *Uranium in Dental Porcelain*; U.S. Department of Health, Education, and Welfare; HEW Publication (FDA) 76-8061, 1976; p 1.
17. Code of Federal Regulations, **1995**, Title 10, Part 40.
18. Raloff, J. *Sci. News* **1991,** *140*, 79.